Outputs of Scientific and Engineering Research: Articles and Patents

The products of academic research include trained personnel and advances in knowledge. Trained personnel are discussed in chapter 4 of this volume and earlier in this chapter. This section presents two sets of indicators of advances in knowledge: articles published in a set of the world's most influential refereed journals (see sidebar, "Data Sources for Article Outputs") and patents awarded to U.S. universities and colleges.

Although academic researchers contribute the bulk of all scientific and technical articles published in the United States, the focus in this section is considerably broader. It includes U.S. articles in all sectors and total U.S. articles in the context of article outputs of the world's nations. The output volume of research, or article counts, is one basic indicator of the degree to which different performers contribute to the world's production of research-based S&E knowledge. The outputs of different U.S. sectors (universities and colleges, industry, government, and nonprofit institutions) indicate the relative prominence of these organizations in the United States overall and in particular S&E fields. The same indicator, aggregated by country, provides approximate information about the U.S. position in the global S&E enterprise and the emergence of centers of S&E activity to stimulate it, especially during the past decade.

Scientific collaboration in all fields increasingly crosses organizational and national boundaries. Articles by multiple authors in different venues or countries provide an indicator of the degree of collaboration across sectors and nations. Scientific collaboration has risen as governments have acted to stimulate it, especially over the past decade. Cross-sectoral collaboration is viewed as a vehicle for moving research results toward practical application. International collaboration, often compelled by reasons of the cost or scope of the issue, provides intellectual cross-fertilization and ready access to work done elsewhere.

The perceived influence of research results to advance the state of knowledge is reflected in citations. Both domestic and international citation patterns are examined in this section. References to scientific and technical articles on patents, which suggest the relatedness of research to presumed practical application, are also examined.

Finally, patents issued to U.S. universities are discussed. They provide another indicator of the perceived utility of the underlying research, with trends in their volume and nature

Data Sources for Article Outputs

The article counts, coauthorship data, and citations discussed in this section are based on S&E articles published in a stable set of about 5,000 of the world's most influential scientific and technical journals tracked since 1985 by the Institute of Scientific Information's (ISI's) Science Citation Index (SCI) and Social Science Citation Index (SSCI). Fields in these databases are determined by the classification of the journals in which articles appear. Journals, in turn, are classified based on the patterns of their citations. (See text table 5-15.)

Text table 5-15.
Classification of Institute for Scientific Information (ISI)-covered journals

Field	Percent of Journals
Clinical medicine	24
Biomedical research	11
Biology	10
Chemistry	7
Physics	5
Earth and space sciences	5
Engineering and technology	8
Mathematics	3
Psychology	6
Social sciences	11
Professional and health sciences[a]	10

[a]These fields have citation patterns strongly linked to social sciences and/or psychology. Appendix table 5-40 lists the constituent subfields (fine fields) of the journals covered here.

See appendix table 5-40. *Science & Engineering Indicators – 2002*

SCI and SSCI appear to give reasonably good coverage of a core set of internationally recognized scientific journals, albeit with some English-language bias. Journals of regional or local importance are not necessarily well covered, which may be salient for the categories of engineering and technology, psychology, social sciences, health, and professional fields, as well as for nations with a small or applied science base.

Articles are attributed to countries and sectors by the author's institutional affiliation at time of authorship. Thus, "coauthorship" or "multiauthorship" here refers to institutional coauthorship; a paper is considered coauthored only if its authors have different institutional affiliations. The same applies to cross-sectoral or international collaborations. For example, a paper written by an American temporarily residing in Britain with someone at his or her U.S. home institution is counted as internationally coauthored, thus overstating the extent of such collaborations. Likewise, an article written by a British citizen temporarily located at a U.S. university with a U.S. colleague would not be counted as internationally coauthored, thus understating the count. All data presented here derive from the Science Indicators database prepared for NSF by CHI Research, Inc. The database excludes all letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

indicating the universities' interest in seeking commercialization of its results.

Publication Counts: U.S. and Worldwide Trends

The volume of articles published in the world's key science and technology (S&T) journals is an indicator of the national output of scientific and technical research in the United States and other countries. These core journals exercise a degree of quality control by requiring articles submitted for publication to undergo peer review, which in turn allows comparison of countries' relative efforts and helps reveal their priorities for scientific research. It also permits insight into both the patterns of collaboration across institutions and national borders and the degree and type of knowledge cited in scientific and technical articles.[30]

On a worldwide basis, scientific articles increased by 14 percent between 1986 and 1999, an average of 1 percent growth per year.[31] By region, the growth trend was disparate, with only the Pacific and Near East registering gains near the worldwide trend. Much of the growth was due to an increase of more than 30 percent in Western Europe, primarily in countries that are members of the Organization of Economic Cooperation and Development (OECD). These OECD countries account for more than 95 percent of Western Europe's output. It is likely that these gains reflect, at least in part, these nations' individual efforts as well as those of the European Union (EU) and other regional programs to strengthen the science base.[32] Many of the smaller and/or newer members of the EU, such as Austria, Belgium, Finland, Greece, Ireland, Portugal, and Spain, had very strong gains during this period. (See figure 5-32 and appendix table 5-41.)

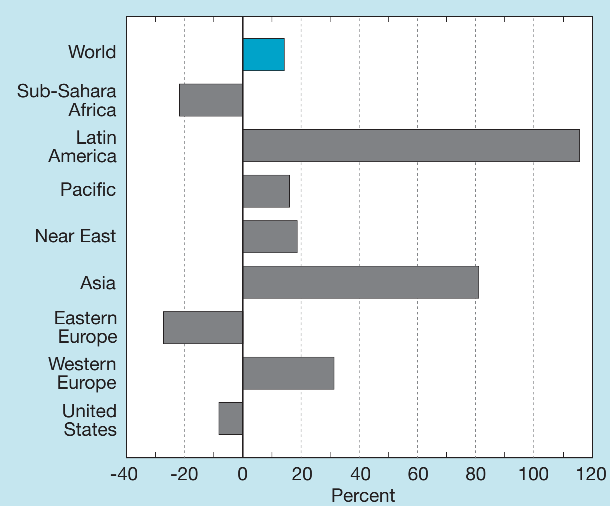
Another region that witnessed very strong gains was Asia, where output nearly doubled during this period, primarily in the eastern half of Asia. This jump in output was driven by Japan, newly industrialized economies (NIEs) (South Korea, Taiwan, Singapore, and Hong Kong), and China. Despite its economic difficulties, Japan's output of articles grew by nearly 50 percent, coinciding with an increase in its R&D expenditures. The collective output of NIEs rose more than sevenfold during this period, coinciding with their rapid economic, technological, and scientific progress. China, a country with a far lower per capita income level compared with NIEs, registered a threefold gain in its publication output. China's economic development has characteristics similar to those of NIEs, as it has rapidly industrialized, adopted economic reform, and increased its expenditures for R&D. In the western half of Asia, output fell during this period by 5 percent due to a 7 percent decrease in India's output, a matter of concern to that nation (see Raghuram and Madhavi 1996).[33]

The largest increase in any region during this period occurred in Latin America, which more than doubled its output. However, this increase was from a low base and concentrated in three countries (Argentina, Brazil, and Mexico), which generated nearly 80 percent of the articles produced by this region in 1999. These countries share the following characteristics: a moderately high per capita income, a relatively large pool of scientists and engineers, and recent reform of their economies and scientific enterprise. In addition, Brazil and Mexico raised expenditures for R&D during the early and mid-1990s.[34]

The Near East, comprising North Africa and the Middle Eastern countries, increased its output by 20 percent during this period. Although Israel, a mature and wealthy industrialized country, dominates output in this region, its growth was stagnant. Excluding Israel, output rose by more than 50 percent during this period. Countries in North Africa, such as Algeria, Morocco, and Tunisia, and in the Middle East, such as Iran, Jordan, and Syria, more than doubled their output of journal articles, although this increase was from a very low base.

Regions whose share of world output decreased were Eastern Europe, Sub-Saharan Africa, and North America. (See

Figure 5-32.
Growth trends in scientific and technical publications by region: 1986–99



See appendix table 5-40. *Science & Engineering Indicators – 2002*

[30] To facilitate comparisons between countries, the numbers reported here are based on the 1985 ISI set of core journals. This set of influential world S&T journals has some English language bias but is widely used around the world. See, for example, Organization of American States (1997) and European Commission (1997). Also see the sidebar, "Data Sources for Article Outputs" in this chapter.

[31] This is a minimum estimate. An expanded 1991 journal set yields an average per annum growth rate of 1.4 percent for the 1990s. In addition, a fixed journal set is biased against growth by excluding the addition of new journals.

[32] These include five-year Framework Programmes of the EU, EU funding provided through Structural Funds, Community Initiatives Programmes, and efforts outside the EU framework such as EUREKA, a program to stimulate partnerships between industry, universities, and research institutes. See NSF (1996) for a brief discussion and European Commission (1997) for a fuller treatment.

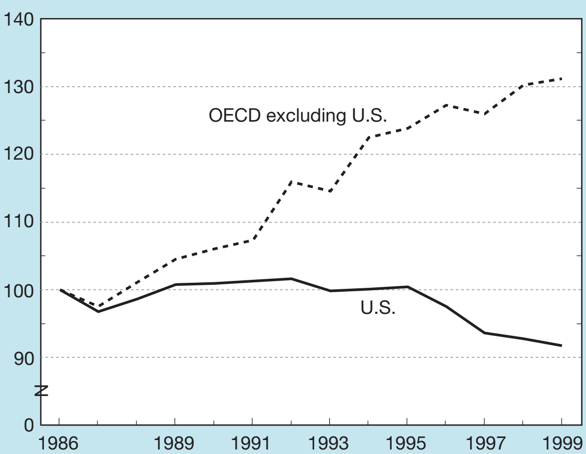
[33] The authors note that this decline cannot be attributed to journal coverage in the SCI and that it is paralleled by a decline in citations to articles by authors from India. They speculate that an aging scientific workforce may be implicated, along with a "brain drain" of young scientists from India whose articles would be counted in the countries in which they reside, not in their country of origin.

[34] See the NSF report, "Latin America: R&D Spending Jumps in Brazil, Mexico, and Costa Rica at <http://www.nsf.gov/sbe/srs/nsf00316/start.htm>.

Trends in U.S. Scientific and Technical Articles

The number of scientific and technical articles by United States authors appears to have peaked in 1992, then fallen throughout the remainder of the 1990s, with output in 1999 down by 10 percent compared to 1992. This trend diverged from growth in most other OECD countries during this period and is a reversal from three prior decades of consistent growth. (See figure 5-33.)

Figure 5-33.
Output of scientific and technical papers for the U.S. and OECD: 1986–99



OECD = Organisation for Economic Co-operation and Development

NOTE: OECD count includes only high income (as defined by the World Bank) members.

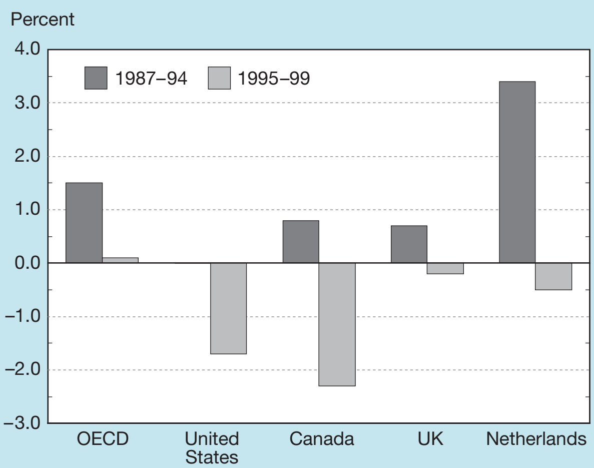
See appendix table 5-41. *Science & Engineering Indicators – 2002*

The 1985 journal set on which much of this chapter's analysis is based is biased against growth because it excludes articles published in journals issued since 1985. However, a larger set of journals from 1991 and 1995 shows similar trends for U.S. scientific and technical articles through the latter half of the 1990s. The reasons for this development remain unknown.

This phenomenon is not limited to the United States. Three industrialized countries with a significant output of publications (Canada, the United Kingdom, and the Netherlands) also experienced a fall in S&T articles during the latter half of the 1990s. (See figure 5-34.) In addition, in the latter half of the 1990s, the growth rate in the output of most other OECD countries slowed relative to the early 1990s.

As shown in text table 5-16, the downward trend in U.S. scientific and technical articles has been broad based, affecting almost all fields:

Figure 5-34.
Average growth in scientific and technical papers for selected countries



OECD = Organisation for Economic Co-operation and Development

NOTE: OECD count includes only high income (as defined by the World Bank) members.

See appendix table 5-41. *Science & Engineering Indicators – 2002*

Text table 5-16.
Change in U.S. output of scientific and technical articles, by fields: 1992–1999

Field	1992–1999 (percent change)	Percentage contribution to total decline
All fields/total	–10	100
Life sciences	–7	41
Clinical medicine	–5	15
Biomedical research	–6	10
Biology	–22	16
Chemistry	–9	7
Physics	–9	9
Earth and space sciences	13	–6
Engineering and technology	–26	19
Mathematics	–10	2
Social and behavioral sciences	–19	28

NOTE: Social and behavioral category consists of the social sciences, psychology, health, and professional fields. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

- The largest decrease in published articles, 26 percent, occurred in the engineering and technical field, which accounted for 19 percent of the overall decline.
- Life sciences accounted for more than 40 percent of the overall decrease in articles. Biology experienced the steepest decrease (22 percent), accounting for 16 percent of the overall decline. Although the decrease in articles in clinical medicine and biomedical research was much smaller (5 and 6 percent, respectively), these two fields accounted for 25 percent of the overall decline due to their preponderant share (49 percent) of scientific and technical articles.
- Output in social sciences and related fields fell 19 percent, accounting for almost one-third of the overall decline.
- Articles in chemistry and physics each decreased by 9 percent during this period, accounting for 16 percent of the overall decline.

Almost all sectors were affected by this trend in S&T articles. Together, the private for-profit sector, which experienced a 24 percent decrease, and the Federal Government, which experienced a 17 percent decrease, accounted for 35 percent of the overall decline. (See text table 5-17.) The decrease in articles produced within academia was less pronounced (9 percent) but, because of the sector's high share of total output, it accounted for 64 percent of the overall decline.

In each of these sectors, several fields were most affected. In academia, almost half of the decrease was in the life sciences; one-third was in the social sciences; and about 15 percent was in the engineering and technical field. The life sciences were also the prime factor in the fall in publications in the Federal Government, accounting for two-thirds of the overall decrease. The engineering and technical field and social sciences contributed to most of the remainder of the lower article output in this sector. In the private sector, more than 80 percent of the decline was in three fields: physics (38 percent), engineering and technical (24 percent), and chemistry (19 percent).

Text table 5-17.
Trend in U.S. scientific and technical articles, by sector: 1992–99
(Percentage)

Sector	Decline	Contribution
Total	10	100
Academia	9	64
Federal Government	17	14
Private	13	20
For profit	24	21
Nonprofit	1	1
FFRDC	1	0
Other	13	3

FFRDC = Federally Funded Research and Development Center

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

Science & Engineering Indicators – 2002

A preliminary review of the reasons behind the trends in the number of U.S. articles examined the following:

- **Methodology.** Article counts for the United States and other countries are based on a fixed set of journals from the 1985 SCI/SSCI database. Unless noted, the journals are counted on a fractional basis, which credits the authors of multiple authored papers their fractional contribution. Although this approach facilitates consistent comparison over time and between countries, it biases against growth, for two reasons: A fixed set of journals excludes new journals that have been added to the SCI/SSCI database. Growth in international collaboration depresses the count of each nation's internationally coauthored papers (because each country's coauthor is credited with a portion of the paper). If counting is done on the basis of the entire SCI/SSCI database and with whole counts, the number of U.S. articles shows growth; however, their growth rate is slowing.
- **Coverage.** The coverage of the SCI/SSCI database may be incomplete or otherwise flawed, a problem shared by all bibliographic databases because of the impossibility of indexing all scientific literature. The SCI/SSCI database, however, has the most complete coverage of any bibliographic database, and it arguably covers the most significant and important peer-reviewed scientific journals. Because only a fraction of scientific literature is considered to be of high quality and important, based on the frequency of citations, the limited coverage of bibliographic databases does not appear to be a major problem for measuring quality scientific publications.
- **Electronic publishing.** The Internet is changing scholarly communication, but whether it is depressing traditional publishing is unclear. The number of peer-reviewed electronic publications has grown rapidly, from 29 in 1993 to 1,049 in 1997.* Although high-quality electronic journals are included in the SCI/SSCI database, it is possible that some publications are missed, especially if these journals are rapidly expanding. One way to ascertain whether electronic publishing is implicated in the U.S. article decline is to see whether established journals are citing electronic journals. An analysis of reference patterns in a sample of 986 papers published in 1990, 1995, and 1997 found few references to Internet URLs. The lack of references

* National Science Board. 2000. *Scientific and Engineering Indicators 2000.* NSB-00-1. Arlington, VA: National Science Foundation, pp. 9–30.

to Internet URLs might indicate that this practice was not very common in 1997.

- **Commercialization of academic science.** Academic science may have become increasingly commercialized over the past two decades. Universities, often in partnership with industry, have moved to commercialize their research through patenting, licensing, and establishing spin-off companies. In this environment, some academic researchers may be delaying or withholding their research because of proprietary concerns. In addition, patenting by academic researchers might absorb time that would otherwise be devoted to publishing. Some research suggests that researchers in the life sciences, which has been the key field in commercialization, delay or refrain from publishing. A 1997 survey of life science researchers found that 30 percent of respondents reported that they delayed or withheld publication of their research due to proprietary concerns.[†] In addition, in a survey of 1,000 technology managers and faculty of top research universities, 79 percent of technology managers and 53 percent of faculty reported that participating firms had asked that certain research findings be delayed or withheld from publication.[‡] Although the number of articles in this field fell at a slower rate than that of the overall decline, this field's predominance meant that it accounted for almost half of the apparent decrease. By sector, it was the major factor in the decline in articles from universities and the Federal Government. However, there appears to be no significant difference in the overall output of articles from universities that are major patenters and those that are not. The change in output of the former between the two three-year periods ending in 1995 and 1999 was –5.4 percent compared with –4.6 percent for the latter.

- **Changes in U.S. R&D funding.** U.S. research funding patterns could explain the decline in article output. It is very difficult or impossible, however, to precisely match funding and publication by field, because the fields are classified and defined differently. In addition, scientists in a given funding field may publish their results in a journal that is classified in a different bibliographic field. For fields in which an approximate match could be made, the findings were inconclusive. For example, the fall in articles in biology and physical sciences coincided with a fall in Federal spending (in real terms) in these two fields. However, increases in funding for physics coincided with a decline in articles. Matching funding and publication by sector is more straightforward, because institutions are classified the same way. However, there appears to be no correlation between these two variables. Basic and applied research expenditures have increased in universities and the Federal Government, but article output has declined in these sectors. However, funding increases in the nonprofit institutions and nonprofit FFRDCs have coincided with increased article output in these sectors. A more precise match between NIH publication output and intramural expenditures reveals that the trend of funding and publication growth diverged in the early 1990s, with publication growth flattening as funding continued to increase.

- **Demography.** The U.S. scientific workforce has aged significantly since the 1970s. In the early 1970s, nearly half of all academic scientists and engineers were younger than age 40. Twenty years later, that figure had fallen to 28 percent, and by 1997, it had dropped to 25 percent. If age affects research productivity negatively, then this factor could provide a plausible explanation.[§] However, the apparent decline in publications did not occur until after this demographic shift had been well under way during the previous two decades.

- **Growth in foreign publishing.** During the 1990s there has been robust growth in foreign-authored publications. Scientific publications indexed to SCI have grown rapidly in many developed and several developing countries, notably in Western Europe, Latin America, and East Asia reflecting the growth in their production of S&E Ph.Ds. In addition, IT developments may have helped to level the playing field for scientists who were isolated or lacked access to relevant journals in their research fields, particularly in developing countries. Because there is limited space for high-quality articles, it may be that foreign publications are displacing U.S. publications. An indication of that possibility is shown by articles published in *Science* magazine. The number of U.S. papers in *Science* decreased by 5 percent between 1994 and 1999, while the total number of papers increased by 9 percent.

These and other factors will be the subject of further assessment of the nature of the trends affecting U.S. articles in the world's premier scientific and technical journals.

[†] Blumenthal, D., E.G. Campbell, M.P. Anderson, N. Causino, and K. Seashore Louis, 1997. "Withholding Research Results in Academic Life Science."

[‡] Florida, R. 1999. "The Role of the University: Leveraging Talent, Not Technology."

[§] Two studies reached different conclusions on this issue. See Blackburn, R. and J. Lawrence. 1986. "Aging and the Quality of Faculty Job Performance." *Review of Educational Research* (Fall): 265–90, and Levin, S., and P. Stephan. 1991. "Research Productivity Over the Life Cycle: Evidence for Academic Scientists." *American Economic Review* (March): 114–32.

figure 5-32 and appendix table 5-41.) Eastern Europe's share of worldwide output fell from 9 to 6 percent during this period. Publication volume in countries of the former Soviet Union dropped by one-third. This decline mirrors the economic and political difficulties that affected their scientific enterprise, including significant cuts in their R&D spending. In contrast, the Eastern European countries (Bulgaria, the Czech Republic, Hungary, Poland, Romania, and Slovakia) experienced a much smaller decrease in articles, and in the mid-1990s, their output began trending upward. In Sub-Saharan Africa, output fell by 20 percent during this period, which reduced this region's share to less than 1 percent of world output. Countries that experienced significant declines included South Africa, which accounts for about half of the region's output, Nigeria, and Zimbabwe. However, several countries, including Cameroon, Cote d'Ivoire, Ethiopia, and Uganda, registered strong gains in their output, although these gains came from a very low base.

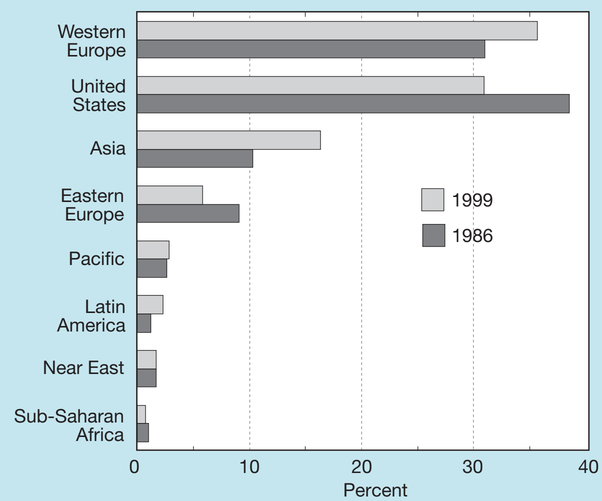
Notwithstanding the trend in the number of U.S. publications (see sidebar, "Trends in U.S. Scientific and Technical Articles"), the United States had the largest single share of worldwide publications in 1999, accounting for approximately one-third of the 530,000 articles in the 1985 SCI set of journals, more than triple the share of the next largest country, Japan. The United States and four other wealthy industrialized countries (Japan, Germany, the United Kingdom, and France) accounted for about 60 percent of worldwide publications in 1999. Japan, Germany, the United Kingdom, and France each had at least a 5 percent share of the worldwide output of articles, and on a per capita basis, their output was comparable with or exceeded that of the United States.

Nevertheless, the combined share of world output of the United States and these four countries declined from 64 to 60 percent during the 1986–99 period, due in large part to the apparent fall in U.S. articles, which reduced the U.S. share from 39 percent in 1986 to 31 percent in 1999. (See figure 5-35). The article share of Western Europe rose from 31 percent to 36 percent of world output during this period due to strong gains by most of these countries.

When the OECD and other high-income countries are added to the United States, Japan, Germany, the United Kingdom, and France, more than 80 percent of world output of the 1985 SCI journal set is accounted for. The predominance of these countries in scientific publications is consistent with their wealthy and technically advanced economies, extensive scientific and technical infrastructure, large pools of scientists and engineers, and comparatively high levels of expenditures for their science and engineering (S&E) enterprises.[35] However, increased S&T publishing in countries such as China, South Korea, Brazil, Mexico, and Argentina has increased the worldwide output of middle- and low-income countries. (See figure 5-36).

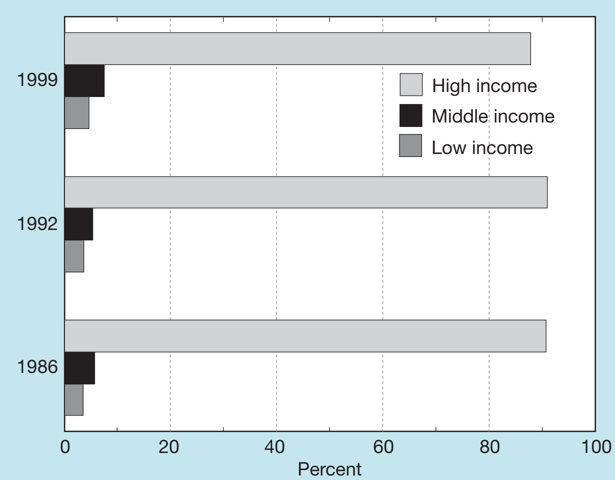
[35] Also see chapter 3, "Higher Education in Science and Engineering"; chapter 4, "U.S. and International Research and Development: Funds and Alliances"; and chapter 6, "Industry, Technology, and the Global Marketplace."

Figure 5-35.
Scientific publications: Regional share of world output



See appendix table 5-41. *Science & Engineering Indicators – 2002*

Figure 5-36.
Country share of world scientific publications, by income level



NOTE: Countries without World Bank income classification and new countries are excluded.

SOURCES: Articles: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Science Indicators database. Country income: The World Bank, World Development Indicators 2000.

Science & Engineering Indicators – 2002

Examining the portfolio of scientific papers across regions and countries provides an indication of the priorities and emphasis of scientific research. The U.S. portfolio is broad and diverse, although dominated by life sciences. This pattern is similar to that of other OECD countries, but for major European nations the physical sciences shares are larger than in the

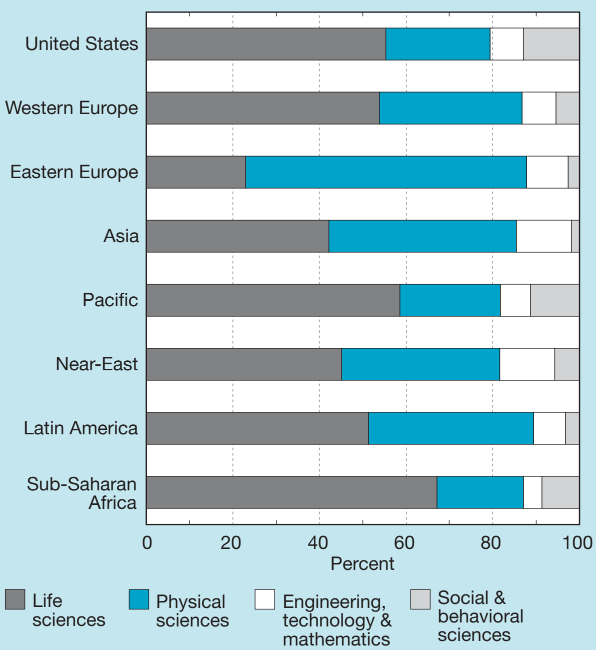
U.S. (See figure 5-37 and appendix table 5-43.) The life sciences (clinical medicine, biomedical research, and biology) accounted for more than half (55 percent) of all U.S. articles published in 1999. Their share has remained roughly constant over the past two decades, with marginal gains by clinical medicine and biomedical research offsetting a small loss by biology. Another one-quarter of the 1999 articles were produced in the physical and environmental sciences (chemistry, physics, and earth and space sciences) and mathematics. These fields registered a slight gain of three points compared with 1986. The remainder of the portfolio is accounted for by engineering and technology (6 percent) and social and behavioral sciences (13 percent), consisting of social sciences, psychology, health, and professional fields. The latter two fields have close ties (based on citations) to the former two fields.

The portfolio distribution in Western Europe and the Pacific is similar to that of the United States, except that physical sciences have greater prominence in Western Europe. (See figure 5-37.) Articles in physical sciences increased slightly in Western Europe between 1986 and 1999, while articles in life sciences decreased. In Asia, the physical sciences and engineering and technical fields were more prominent and life sciences and social sciences less so, especially in NIEs, China, and India. In these countries, life sciences accounted for one-quarter of the portfolio and physical sciences for more than half. The portfolios of the Asian NIEs underwent sizable shifts, with the share of physical, engineering and technical, and mathematical sciences growing dramatically from 40 percent of total output to more than 54 percent, largely due to an 11 percent share increase by physics. During the same period, the share of social and behavioral sciences declined from 12 to 3 percent. In contrast, Japan's portfolio is closer to that of Western Europe, with greater emphasis in life sciences (half of all articles) and less emphasis in the engineering and technical field.

In Eastern Europe and the former Soviet Union, the portfolio mix is similar to that of Asia, with physical sciences accounting for more than half of the total article output. The portfolio has shifted notably during this period; the share of life sciences declined from 36 to 23 percent, while that of physical sciences rose from 56 to 65 percent. The Near East region's portfolio is similar to that of Asia and Eastern Europe, with greater prominence of articles in physical sciences, which have increased relative to life sciences over the past two decades. Sub-Saharan Africa has the highest regional share of output in life sciences in the world (67 percent) and the smallest share in engineering and technology. The portfolio mix in Latin America is similar to that of Western Europe, with life and physical sciences being prominent, although the mix has shifted to a greater share for physical sciences relative to the life and social sciences.

In the United States, universities were the primary institutional source of publications (74 percent) in 1999, followed by much smaller shares from the Federal Government (7 percent), private for-profit (8 percent), private nonprofit (7 percent), and federally funded research and development centers (FFRDCs) (3 percent). (See figure 5-38.) Examining the data by field of science shows that the academic sector produced a greater-than-average share of articles in the fields of biomedical research, mathematics, and the social and behavorial sciences. Industry articles were prominent in physics, engineering and technology, and chemistry. Articles published by the Federal Government were prominent in the fields of biology, clinical medicine, and earth and space sciences. The nonprofit's portfolio was dominated by clinical medicine.(See appendix table 5-44).

Figure 5-37.
Portfolio distribution of scientific and technical publications, by region: 1999



NOTES: Life sciences consist of clinical medicine, biomedical research, and biology. Physical sciences consist of chemistry, physics, and earth and space sciences. Social and behavioral sciences consist of social science, psychology, health, and professional fields. Computer sciences is included in engineering and technology.

See appendix table 5-43. *Science & Engineering Indicators – 2002*

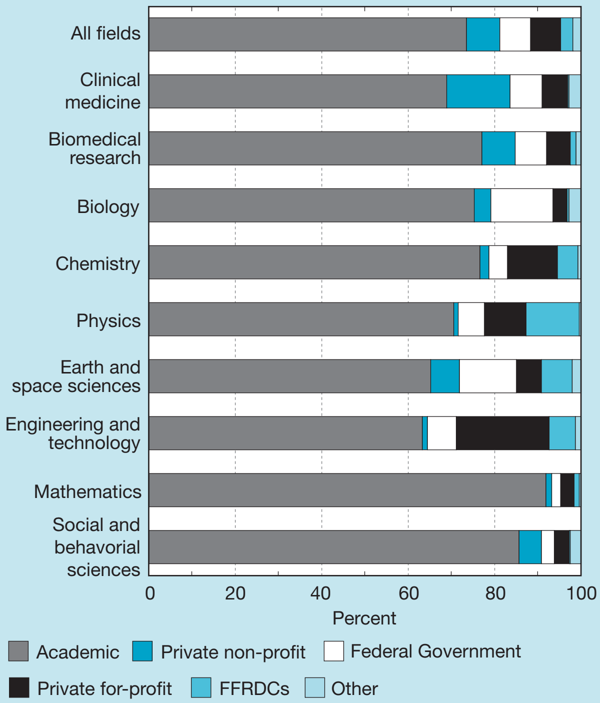
Scientific Collaboration

Scientific collaboration within and across national borders has increased significantly in the last two decades. Worldwide, more than half of all articles were coauthored[36] in 1999 compared with 37 percent in 1986. During the same period, the share of internationally coauthored articles rose from 7 to 17 percent of all publications; i.e., more than one-third of coauthored articles were internationally coauthored. Several factors have been driving the rise in collaboration:

- **IT.** Advances in IT have helped to reduce the geographical and cost barriers to domestic and international collaboration. E-mail greatly facilitates collaboration by allowing rapid exchange of information and eliminating the need for costly face-to-face meetings. The increasing use of high-capacity networks allows researchers to exchange

[36]A paper is considered co-authored when it has authors from different institutions. "Internationally coauthored" papers have at least one international institutional author. See "Data Sources for Article Outputs" on pg. 56-57.

Figure 5-38.
U.S. authorship, by sector: 1999



FFRDCs = Federally Funded Research and Development Centers

NOTES: Social and behavorial sciences consist of social sciences, psychology, health, and professional fields. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; National Science Foundation, Division of Science Resources Statistics.

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huge data files, and improvements in software permit researchers to share research findings or conduct research on-line without requiring a centralized laboratory. (See also the “IT and R&D” section in chapter 8).

♦ **Economic growth.** Technology is increasingly recognized as a key determinant of economic growth by most nations, and the lag between scientific research and practical applications appears to have narrowed. In an environment of liberalization of trade and investment, scientific collaboration allows countries to acquire scientific and technological proficiency to maintain their competitive advantage or compete in new markets. For established scientific nations, domestic and international collaboration affords benefits such as cost savings, the potential to make faster progress, the ability to apply different or multidisciplinary approaches to problems, and the ability to stay abreast of advances made in related fields and other countries. Domestic and international collaboration allows nations with smaller or less developed S&T systems, to leverage and boost their indigenous capacity and provides a means to acquire knowledge from more advanced nations.

♦ **Scale, cost, and complexity of scientific research.** As the scale, cost, and complexity of attacking many problems have increased, research teams have become common, changing the structure of the research. Cutting-edge science in many fields increasingly involves a broad range of knowledge, perspectives, and techniques that extend beyond a given discipline or institution. Moreover, the scale, cost, and complexity of some of today’s scientific problems, such as mapping the human genome, studying global environmental trends, or constructing an observatory in space, invite or often compel domestic and international collaboration.

♦ **Politics.** The end of the cold war has allowed countries to establish and/or renew political, economic, and scientific ties that previously were not possible. The dissolution of the former Soviet Union also increased the number of collaborating countries. In addition, a web of intergovernmental agreements invites or requires multinational participation in some research activities.

♦ **Education.** The extent of the advanced training students receive outside their native countries also appears to be a factor.[37] Relationships established between foreign students and their teachers can form the basis of future collaboration after the students return to their native countries. IT facilitates this type of collaboration.

Collaboration Within the United States

Work produced by single authors is in decline in virtually all fields, and the proportion of U.S. scientific and technical articles by multiple authors has continued to rise. In 1999, 60 percent of all S&E articles had multiple authors, up from 48 percent in 1988. This reflected an approximate 30 percent decrease in the number of U.S. articles by single authors and a corresponding increase in the number of articles by multiple authors. This general pattern held for all but psychology and social and behavioral sciences; in that group output by authors from the same institution fell and from authors from multiple institutions was static. (See appendix table 5-45.) Multiple authorship was highest in clinical medicine, biomedical research, earth and space sciences, and physics (ranging from 63 to 69 percent), and lowest in the social sciences, psychology, and chemistry (ranging from 35 to 48 percent).

Collaboration across institutions in the United States is extensive. The Federal Government has long sought to stimulate this trend in several ways, for example, by promoting collaboration across sectors (e.g., industry-university or FFRDC-industry activities). Such cross-sector collaboration is seen as enriching the perspectives of researchers in both settings and as a means for more efficiently channeling research results toward practical applications.

In 1999, cross-institution or -sector collaboration (the share of multi-authored papers authored in different sectors as a percentage of all multi-authored papers was 77 percent or greater for all institutions except the academic sector. (Text

[37]See chapter 3, “Higher Education in Science and Engineering.”

Text table 5-18.
U.S. sector cross-collaboration: 1999
(Percentage)

Sector	Share of sector's coauthored papers with other sectors	Share of sector's cross-sectoral collaborated papers: Academic	Federal Government	Private for-profit	Private nonprofit	FFRDC	Other government
Academic	37	NA	32	25	36	13	6
Federal Government	81	87	NA	14	14	6	3
Private for profit	77	82	17	NA	16	7	2
Private nonprofit	79	90	13	13	NA	3	3
FFRDC	80	85	14	14	7	NA	0
Other government	92	86	19	11	20	1	NA

FFRDC = Federally Funded Research and Development Center, NA = not applicable

NOTES: Shares based on whole counts of publications, where each institutional author is assigned a whole count. This counting methodology results in the sum of sector shares exceeding 100 percent because some coauthored papers involve collaboration across more than two sectors. FFRDC includes FFRDCs administered by university, industry, and nonprofits.

See appendix table 5-46.

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table 5-18 and appendix table 5-46.) The academic sector was at the center of cross-sectoral collaboration in every sector and field, although the academic sector itself had a much lower cross-sectoral share (37 percent), because the majority of its collaboration occurred among institutions of higher education. Cross-sector coauthorship rates with academia (the percentage of a sector's cross-sector coauthored papers with an academic collaborator) were at least 82 percent for other sectors.

Distinct collaborative relationships exist by field of science, as measured by the share of cross-institutional papers:

♦ **Clinical medicine.** This field is characterized by a high degree of collaboration across institutions (as well as a high share of multiauthored papers). Important partnerships in this field include universities and the Federal Government with nonprofit organizations and FFRDCs and the Federal Government and nonprofit organizations.

♦ **Biomedical research.** The private sector is a key collaborator with other institutions, with nonprofits authoring papers with academia and the FFRDCs and industry partnering with the Federal Government and nonprofits.

♦ **Biology.** Although the proportion of multiauthored papers is lower than for other life sciences, cross-institutional papers are a significant share of these multiauthored papers. Similar to biomedical research, the private sector is a key collaborator, authoring papers with the Federal Government, academia, and nonprofits. In addition, academia and the FFRDCs are significant collaborators.

♦ **Chemistry.** Industry is a key collaborator, authoring papers with nonprofit organizations, academia, and the Federal Government.

♦ **Earth and space sciences.** This field has the highest share of multiauthored papers, including collaboration across sectors. The Federal Government and FFRDCs have prominent ties to the private sector in this field.

♦ **Engineering and technology.** This field is similar to biology, with a lower share of multiauthored papers but a higher-than-average share of cross-sector papers. Industry is a collaborator with academia, FFRDCs, and the Federal Government. In addition, FFRDCs have prominent ties with the academic sector.

♦ **Physics.** The Federal Government has prominent ties to FFRDCs and industry in this field.

International Collaboration

International collaboration increased greatly over the past two decades, as indicated by multiauthor articles with at least one international author. From 1986 to 1999, the total number of internationally coauthored articles increased by 14 percent, while multiauthored papers rose by 65 percent, raising the share of multiauthor articles from 37 percent to more than half of total publications. Internationally coauthored papers nearly tripled in volume, raising their share from 20 to 32 percent of multiauthored papers. In 1999, 17 percent of scientific articles had at least one international author.

Patterns of international coauthorship provide one indication of the extent of collaborative ties among nations and regions. By this indicator, several trends in international collaboration are evident:

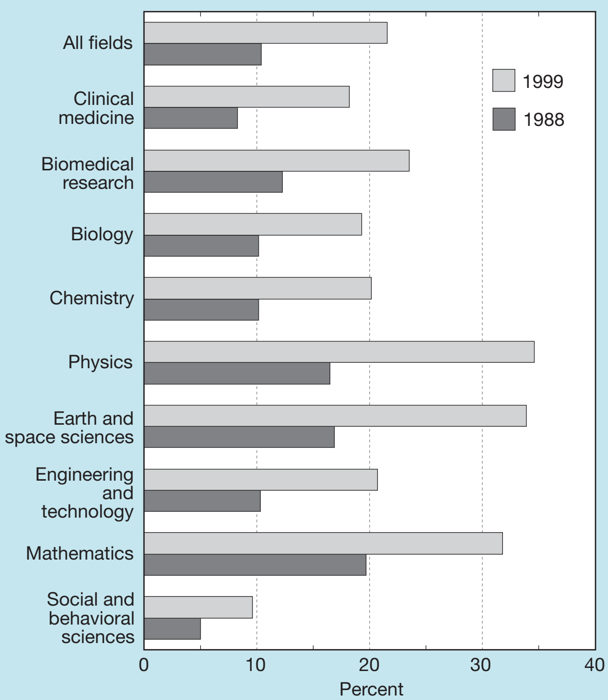
♦ The dominant centers in the production of S&T papers, the United States, Western Europe, Japan, and several other Asian countries, are centers of international scientific collaboration. A substantial part of these countries' international collaboration is with the other countries in this group.

♦ The remaining regions of the world with largely developing and emerging economies (Eastern Europe, the Near East, North and Sub-Saharan Africa, and Latin America) conduct most of their collaboration outside their regions with the United States, Western Europe, and Asia.

U.S. International Collaboration. Almost all the increase in coauthored U.S. articles reflected rising international collaboration. By 1999, 1 article in 5 had at least one non-U.S. author, compared with 1 article in 10 in 1988. (See figure 5-39.) Rates of international coauthorship were highest for physics, the earth and space sciences, and mathematics, ranging from 32 to 35 percent of all U.S. articles. International collaboration rates were much lower (10 percent) in social and behavioral sciences.

United States authors participate prominently in international collaborations. In 1999, 43 percent of all published papers with at least one international coauthor had one or more U.S. authors. U.S.-international coauthorships encompass not only the world's major scientific countries but also many developing and emerging economies. This included countries with low overall rates of international collaboration. In 1999, U.S. researchers published collaborative scientific papers with researchers from 160 countries—almost every country in the world that authored international scientific papers. (See appendix table 5-47).

Figure 5-39.
U.S. international collaboration, by field



NOTES: Social and behavioral sciences consist of social science, psychology, health, and professional sciences. Computer science is included in engineering and technology. Field volume is in terms of whole counts, where each collaborating institutional author is assigned an entire count.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

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With few exceptions, U.S. coauthorship with Western Europe is extensive. This share ranged from 23 to 35 percent, including the three Western European countries with the highest output of scientific publications: the United Kingdom (29 percent), Germany (30 percent), and France (25 percent). (See text table 5-19 and appendix table 5-48.) U.S. coauthorship

Text table 5-19.
International coauthorship with the United States: 1986 and 1999
(Percentage)

Country/economy	U.S. share of country's internationally coauthored articles 1999	1986
Taiwan	60	67
South Korea	57	67
Israel	53	68
Canada	51	53
Mexico	43	56
Japan	42	56
Brazil	40	38
India	37	37
Kenya	37	36
New Zealand	37	38
Australia	37	40
Uganda	36	36
Turkey	35	40
Chile	35	47
Egypt	34	40
Singapore	33	28
Italy	32	36
Switzerland	32	32
South Africa	32	37
Argentina	30	44
China	30	51
Germany	30	35
Netherlands	30	30
United Kingdom	29	35
Hong Kong	29	64
Norway	29	29
Finland	28	34
Denmark	28	28
Hungary	28	25
Sweden	27	36
Poland	25	21
Russia	25	na
Spain	25	29
France	25	29
Ireland	25	24
Belgium	23	28
Czech Republic	22	na
Nigeria	21	34
Ethiopia	18	13
Malaysia	10	24

na = not applicable

NOTES: U.S. internationally coauthored articles involve at least one U.S. author. Countries ranked by share in 1999.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

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rates with Asia were generally higher than with Western Europe, ranging from 30 to 60 percent (with a few exceptions) of each country's internationally coauthored papers. U.S. collaboration was especially high with NIEs (Taiwan at 60 percent, South Korea at 57 percent, and Singapore at 33 percent); China at 30 percent; and two countries that have low overall rates of international collaboration, Japan at 42 percent and India at 37 percent. U.S. coauthorship rates with Latin American countries were similar to those of Asia, ranging from 20 to 60 percent in most countries in this region. This includes the countries of Argentina and Brazil, which have a significant share of regional output but a lower overall rate of international coauthorship than other countries in this region.

U.S. coauthorship rates with Sub-Saharan Africa and the Near East varied widely, from less than 10 percent to greater than 60 percent. However, the United States tended to have a relatively high rate of collaboration with countries that have significant regional output, such as Israel (53 percent), Egypt (34 percent), Kenya (37 percent), and South Africa (32 percent) U.S. coauthorship rates with Eastern Europe were lower, generally ranging from 15 percent to 38 percent, such as Hungary (28 percent), Poland (25 percent), Russia (25 percent), and the Czech Republic (22 percent) in 1999.

The countries which had the highest rate of collaboration with the U.S., as measured by their share of U.S. international articles, were largely those with mature S&T systems. Of the top 10 countries, 6 are in Western Europe; Germany (14 percent), the United Kingdom (12 percent), France (9 percent), Italy (7 percent), Switzerland (4 percent), and the Netherlands (4 percent). (See text table 5-20.) Japan is also a significant collaborator, with a 10 percent share of U.S. international papers. Of these countries, Germany, the United Kingdom, Japan, and France have the highest worldwide share of output after the United States. Canada and Australia are significant collaborators, with shares of 11 and 5 percent, respectively. Russia, with a share of 4 percent, rounds out the top 10 countries.

Little change occurred in these countries' shares of articles coauthored with the United States as compared with the previous decade, except for Russia, which established strong institutional partnerships with the United States during that period. Another important change in U.S. ties is the growing partnership with the Asian NIEs. Although no single NIE is among the top 10 countries, the NIEs have collectively increased their share of U.S. international articles from 2 percent in 1986 to 6 percent in 1999. The patterns of U.S. collaboration with the rest of the world also appear to reflect the ties of foreign students who received advanced training in the United States. (See figure 5-40.)

Compared with the previous decade, U.S. international collaboration declined slightly, falling from 51 percent in 1986 to 43 percent in 1999, as the volume of internationally coauthored papers expanded at a rate faster than the strong growth rate of U.S. coauthored international papers in almost all countries. This pattern, a robust expansion of U.S. coauthored papers accompanied by declining U.S. shares, held for almost all countries. This pattern suggests that new centers of activity and collaboration are evolving.

International Collaboration in the Rest of the World. International collaboration in the rest of the world followed trends similar to those of the United States. In most countries, the number of articles with multiple authors, especially those with at least one international coauthor, grew faster than the number of articles with single authors. This was generally due to an expansion in the volume of internationally coauthored articles and an increase in the number of collaborating countries. The scope of international collaboration among other nations can be seen in appendix table 5-47, which shows the total number of countries with any collaborating nondomestic author on a given nation's papers.

Text table 5-20.
U.S. international papers: top collaborating countries
(Percentage)

	1986			1999	
Rank	Country	Share	Rank	Country	Share
1	Canada	13.6	1	Germany	13.8
2	United Kingdom	13.3	2	United Kingdom	12.4
3	Germany	11.7	3	Canada	11.2
4	France	8.3	4	Japan	9.9
5	Japan	8.1	5	France	8.7
6	Israel	6.3	6	Italy	6.9
7	Italy	5.5	7	Australia	4.5
8	Switzerland	4.1	8	Switzerland	4.3
9	Sweden	4.0	9	Netherlands	4.2
10	Australia	3.9	10	Russia	4.1

NOTES: U.S. internationally coauthored articles involve at least one author from indicated countries. Countries ranked by share in 1999.

SOURCES: Institute for Scientific Information, Science and Social Science Citation indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

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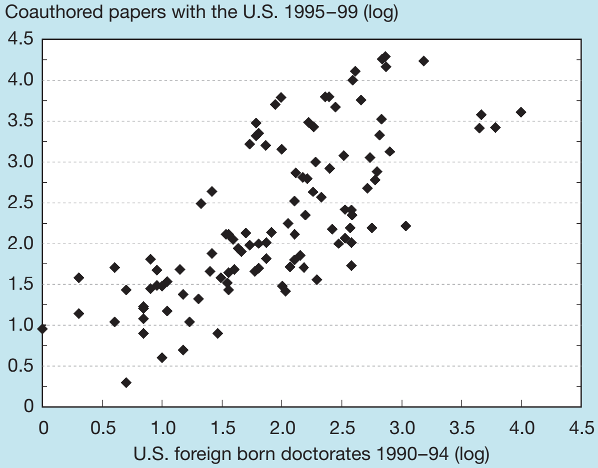
Figure 5-40.
Relationship of foreign-born U.S. doctorates to their country's scientific collaboration with the U.S.



NOTE: This figure includes countries that have at least a .01 percent share of all internationally coauthored papers.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics. Ph.D's: National Science Foundation, Survey of Earned Doctorates.

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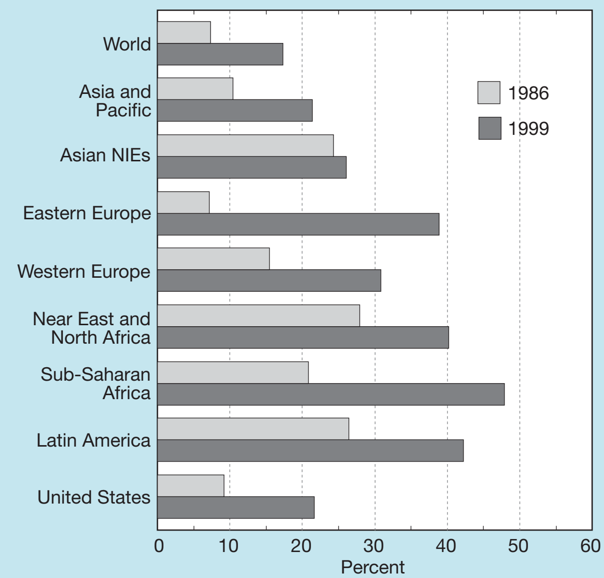
Figure 5-41.
International scientific collaboration by region



NOTES: Asian NIEs are the newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. Asia & Pacific excludes these countries.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

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The table reveals a dramatic expansion of cross-national collaboration over the 13 years due to the creation of new countries and an increase in the number of partnerships with existing countries. A total of 50 countries (including 6 new nations) had ties to at least 50 or more other nations in 1999 compared with 15 in 1986.

The strong growth of collaborative activity occurred in developing and industrialized countries in every region. (See figure 5-41.) In Western Europe, articles by multiple authors rose strongly, increasing their share from 41 percent in 1986 to 60 percent of all publications in 1999. This increase was driven by a rise in internationally coauthored articles, which nearly tripled during this period. By 1999, articles with at least one international coauthor accounted for 31 percent of all publications, up from 16 percent in 1986. Countries in this region, many of which had extensive ties during the previous decade, continued to expand their partnerships. There were 8 Western European countries with ties to 100 or more nations in 1999, an evident sign of this region's extensive scientific collaboration with other nations. Much of the high degree of international collaboration in Western Europe reflects the extensive amount of intraregional collaboration among these countries. Intraregional collaboration increased in virtually all Western European countries between 1986 and 1999, as measured by the share of the countries' international papers with coauthored papers from other European countries. For example, the share of France's international papers with German coauthors increased from 11 to 15 percent; its share with coauthors from the United Kingdom increased from 11 to 14 percent; and its share with Italian coauthors rose from 8 to 11 percent. (See appendix table 5-49.) Outside their region, the Western European countries had a high degree of collaboration with the United States, Eastern Europe, and Asia, especially Japan.

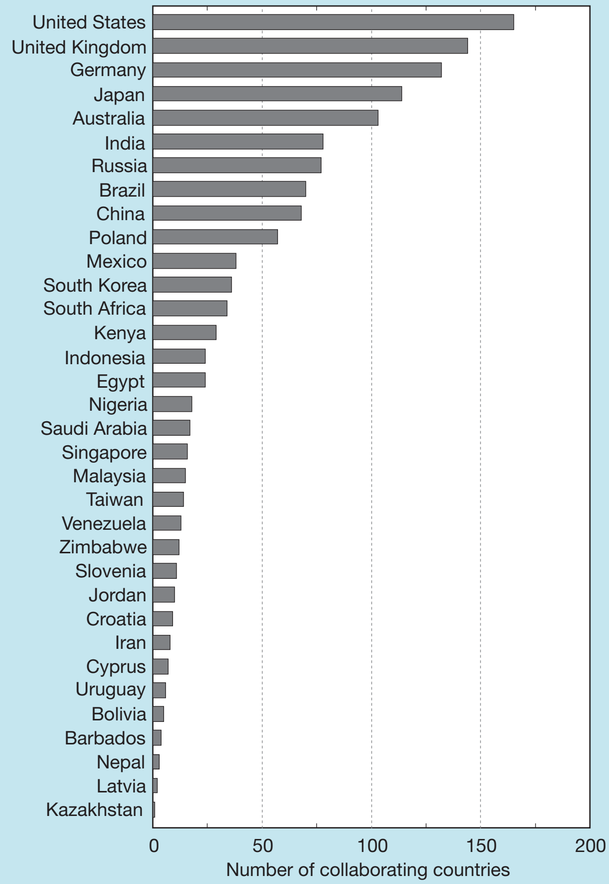
In Eastern Europe and central Asia, internationally coauthored articles grew during this period from less than 10 percent to almost 40 percent of these regions' articles. This jump in international collaboration reflects both a continuation of ties among countries that were part of the former Soviet Union and new partnerships with the rest of the world, especially scientifically advanced countries. For example, roughly one-quarter each of internationally coauthored papers in Russia and the Eastern European countries have at least one author from the United States or Germany. The Baltic states have developed strong collaborative ties with the Nordic states, reflecting the reestablishment of historical and regional connections.

In Asia and the Pacific (excluding the Asian NIEs), multiple authorship more than tripled during this period, largely due to an increase in international articles in these regions from 10 to 21 percent. The share of internationally coauthored papers in NIEs was also significant, accounting for more than one-quarter of their publications. Several Asian countries (Hong Kong, Singapore, Indonesia, and Malaysia) expanded their international ties threefold during this period, and India increased its ties to more than 100 countries in 1999. Greater intraregional collaboration was a significant factor in the increase in international collaboration, especially in China, NIEs, India, and other countries. (See appendix table 5-49.) For example, China's share of articles coauthored with Japan, Singapore, and South Korea rose from 12 to 16 percent, less than 0.5 to 3 percent, and 0.5 to 2 percent, respectively. Japan's rate of intraregional collaboration is much lower, but it also increased its partnerships with other countries in this region, notably with South Korea (from 2 to 5 percent) and China (from 4 to 7 percent). India is similar to Japan in its relatively low level of intraregional collaboration; however, its share of internationally coauthored articles with China, Japan, and the Taiwanese economy did rise. A high degree of collaboration outside the region occurs with the United States and Western Europe.

Gains in international collaboration led to a marked increase in coauthorship in Latin America and Sub-Saharan Africa. In 1999, the share of all papers in the region that were coauthored by at least one international author was nearly half in Sub-Saharan Africa and more than 40 percent in Latin America. These rates were substantially higher than in the previous decade. Intraregional collaboration among the Latin American countries also increased but remained modest in comparison with Western Europe or Asia. (See appendix table 5-49.) Argentina's share of papers coauthored with Mexico rose from 1 to 5 percent, and its share with Chile rose from 3 to 4 percent; however, its share with Brazil, its largest collaborator, fell by 3 percentage points, to 13 percent. Brazil's share with other countries in the region showed little change during this period, and its small shares with other countries attest to its pattern of collaborating largely outside the region. Mexico's collaboration increased with countries such as Argentina, Brazil, and Chile. Outside their own regions, these countries collaborate mainly with the United States and Western Europe, reflecting the importance of partnering with advanced countries with which they have educational, historical, and cultural ties.

Although international ties have expanded greatly, figure 5-42 shows that many countries tend to concentrate their collaborations in relatively few countries, most of which are developed countries with mature S&T establishments. The sharp drop-off in the number of countries collaborated with suggests that developing countries restrict much of their collaboration to major science-producing nations. The rise in intraregional collaboration in most developing regions suggests that their collaboration outside major science-producing nations is confined to developing countries in their own regions. It also suggests that countries with ties to large numbers of other countries, mainly those with a well-developed S&T infrastructure, conduct a large share of their collaboration with other major science producers, and their share with developing nations is a much lower portion of their total collaboration.

Figure 5-42.
Breadth of international scientific collaboration by country: 1999



NOTE: Number of countries that shared at least 1 percent of their internationally coauthored papers with indicated country.

See appendix table 5-47. *Science & Engineering Indicators – 2002*

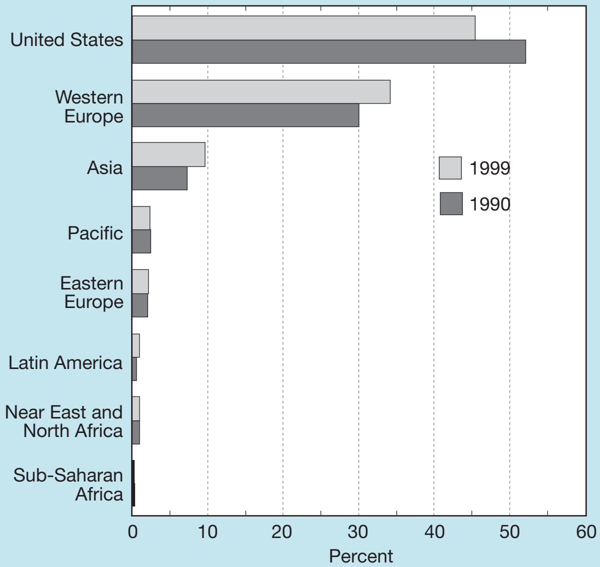
International Citations to Scientific and Technical Articles

The global dimensions of scientific activity, discussed above in terms of international research collaboration, also are reflected in the patterns of citations to the literature. Scientists and engineers around the world cite previous work done elsewhere to a considerable extent, thus acknowledging the usefulness of this output for their own work. Citations, aggregated here by region, country, and field, thus provide an indicator of the perceived influence of a nation's scientific outputs to other countries' scientific and technical work.[38] Citations to the work done in one's own country are generally prominent and show less of a time lag than citations to foreign outputs.

Citations within scientific papers to scientific research are dominated by the major science paper producers: the United States, Western Europe, and Asia. (See figure 5-43.) Scien-

[38]Citations are not a straightforward measure of quality because of self-citations by authors; authors citing colleagues, mentors, and friends; and a possible non-linear relationship of a country's number of publications and citations to that output.

Figure 5-43.
Scientific research cited by scientific and technical papers, by region



See appendix table 5-47. *Science & Engineering Indicators – 2002*

Text table 5-21.
Relative prominence of citations to U.S. scientific publications, by region

	Relative citation index	
Citing country/region	1990	1999
World	1.36	1.35
United States	1.84	1.94
Western Europe	0.98	1.02
Asia and Pacific	0.95	0.99
Asian NIEs	1.07	1.10
Eastern Europe	0.78	0.78
Near East	1.15	1.08
Latin America	1.04	0.97
Sub-Saharan Africa	0.82	0.85

NOTES: Asian NIEs are the newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. Relative citation indexes are frequency of citations to U.S. literature by each region adjusted for U.S. share of scientific papers. A value of 1.00 would indicate that the U.S. share of cited literature is equivalent to the U.S. share of published literature in the world.

SOURCE: CHI Research, Inc.

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tific research from these regions accounts for nearly 90 percent of all cited research. U.S. literature is the most widely cited, although its share fell in the last decade from 52 percent in 1990 to 45 percent in 1999, a decline similar in magnitude to that of the fall in its world share of scientific literature. Meanwhile, the share of cited literature from Western Europe and Asia grew during this period at a magnitude comparable to that of the rise in their share of scientific papers. The increase in the shares of these two regions was driven by many of the same countries that increased their production of scientific papers. In Western Europe, countries such as Germany, France, Italy, Switzerland, the Nordic countries, Spain, and Portugal increased their world share of cited literature. (See appendix table 5-50.) In Asia, the rise in share was driven by countries such as Japan and China and by NIEs. Latin America, which had the fastest growth rate in scientific papers, was the only developing region whose world share of cited literature rose, increasing from 0.6 percent in 1990 to 1 percent in 1999.

Adjusted for its world share of scientific papers, U.S. literature is the most often cited in the world compared with other regions. Over the past two decades, on average, the U.S. share of cited scientific research has been 35 percent greater than the U.S. share of scientific literature. Although the world share of U.S. literature and citations to U.S. literature have declined, the perceived influence of U.S. science remains high on a relative basis. (See text table 5-21 and appendix table 5-51.) The prominence of cited U.S. literature reflects, to a considerable extent, the even higher propensity of U.S. scientists to cite their own literature. U.S. literature, however, is the most highly cited literature by most other regions of the world and is especially prominent in Western Europe, the Near East, and the Asian NIEs. Western European literature is also highly cited by the United States and other regions, especially by Eastern Europe. Although U.S. and Western European literature are generally the most highly cited by developing regions, Latin America and Sub-Saharan Africa each cite the other's literature at a fairly high rate.

Text table 5-22.
Relative prominence of cited scientific literature, by country

Rank	Country	1990	1999
1	Switzerland	1.46	1.37
2	United States	1.36	1.35
3	Netherlands	1.13	1.12
4	Sweden	1.14	1.07
5	Denmark	1.03	1.04
6	United Kingdom	1.06	1.04
7	Finland	0.89	1.02
8	Germany	0.99	1.01
9	Canada	0.93	0.99
10	Belgium	0.98	0.95
11	France	0.94	0.93
12	Austria	0.94	0.91
13	Italy	0.81	0.88
14	Australia	0.94	0.87
15	Israel	0.80	0.84

NOTES: Countries ranked by their relative citation index in 1999. Relative citation indexes are the citations by the world's scientific papers to the country's scientific literature, adjusted for the country's share of scientific papers. A value of 1.00 would signify that the country's share of cited literature is equivalent to its share of published literature in the world.

See appendix table 5-51. *Science & Engineering Indicators – 2002*

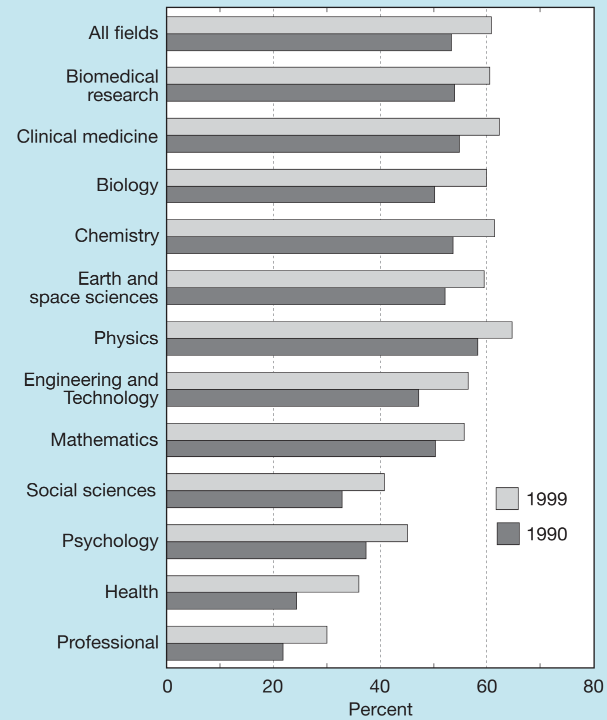
Adjusted for country share of world literature, the most frequently cited countries are major science producers and members of OECD (see text table 5-22 and appendix table 5-52):

- Switzerland is the most highly cited country in the world and is the largest producer of scientific papers on a per capita basis. (See appendix table 5-42.) It is the top-cited country in engineering and technology (with an especially high index of 1.8) and biology, and shares the top spot with the United States in biomedical research.
- The United States is a close second to Switzerland, with U.S. papers the most frequently cited in physics, clinical medicine, biomedical research (tying with Switzerland), chemistry, and earth and space sciences. It is also highly cited in the social and behavioral sciences. Citations to U.S. literature are relatively fewer in biology compared with other fields.
- The Nordic countries, the Netherlands, and Denmark also are very highly cited countries across many fields of science.
- The United Kingdom is highly cited in social and behavioral sciences, along with the United States.

In contrast to OECD countries, developing and emerging countries are cited 25–75 percent less relative to their worldwide share of literature. Despite the high growth rates in article output in NIEs and China, their relative citation indexes, which are at 0.6 or less, did not rise in the 1990s. (See appendix table 5-52.) The lack of increase in the citation of their literature may reflect, in part, that their international ties have been concentrated with the United States and within their own regions. Another difference is that developing countries cite publications produced in their own regions at a much higher rate than do developed countries. For example, the self citation indexes in Latin America (11.4) and Sub-Saharan Africa (32.0) are much higher than their interregional citation indexes. (See appendix table 5-51.) This suggests that these regions lack access to scientific research outside their own regions, although important differences exist between them. Latin America's self-citation index fell markedly during the last decade, whereas its world share of citations increased, suggesting that this region increased its access to international science and that the perceived influence of Latin American research also increased in the rest of the world. Sub-Saharan Africa, on the other hand, continued to have a very high self-citation rate, but its rate of citation in the rest of the world improved only slightly. Although developing and emerging countries are less prominently cited across all fields, certain countries do have particular prominence, adjusted for their share of literature, that rivals that of OECD countries. For example, Chile is the second most-cited country in earth and space sciences, the Hong Kong economy is highly cited in chemistry and biology, and Slovenia is highly cited in mathematics.

The international nature of scientific research, as evidenced by the degree of international collaboration discussed in the previous section, is underscored by the high and growing share of citations to work done abroad. Averaged across all countries and fields, 61 percent of all citations in 1999 were to foreign research compared with 53 percent in 1990. (See figure 5-44.) This overall rate masks a much lower citation rate by the United States compared with much higher rates in the rest of the world. (See appendix table 5-53.) Many of the citations to foreign science are to publications outside each region, primarily to the publications of regions with a well-developed science base: the United States, Western Europe, and to some extent, Asia and the Pacific. The exception to this is Western Europe, where about half of the citations are intraregional, consistent with the region's high degree of intraregional collaboration. The rate of citing foreign science varies by field, with high shares in physics, mathematics, and engineering and technical fields, and the lowest shares in the social and behavioral sciences.

Figure 5-44.
Citations to foreign articles in the world's major scientific and technical journals, by field: 1990 and 1999



NOTES: Citations are for a three-year period with a two-year lag; for example, 1999 citations consist of 1999 articles citing articles published in 1995–97. Computer science is included in engineering and technology.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, Division of Science Resources Statistics.

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Citations in U.S. Patents to Scientific and Technical Literature

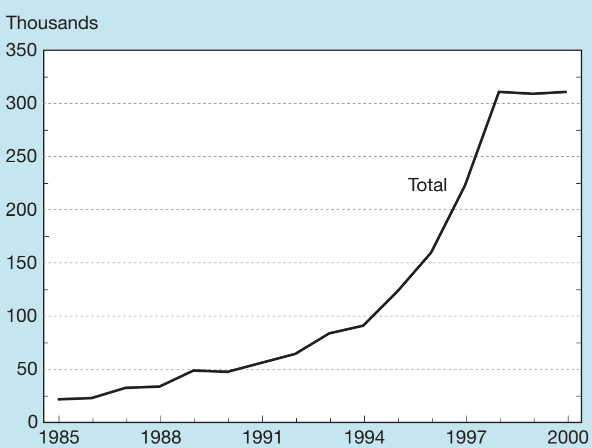
Patent applications cite "prior art"[39] that bounds the inventor's claims to the product or process to be patented. Citations to prior art have traditionally been to other patents; increasingly, these citations include scientific or technical articles. The percentage of U.S. patents that cited at least one such article increased from 11 percent in 1985 to 24 percent in 1997, before falling to 21 percent in 2000.[40] This development attests to both the growing closeness of some research areas, for example, life sciences, to practical applications and the increasing willingness of the U.S. Patent and Trademark Office (PTO) to award "upstream" patents, that is, research-driven products and processes that have less immediate commercial application, such as genetic sequencing. Thus, citations of scientific and technical articles provide an indicator of the growing link between research and innovative application, as judged by the patent applicant and recognized by PTO.[41]

[39]A U.S. Patent application is evaluated on whether it is useful, novel, and non-obvious. The novelty requirement leads to references to other patents, scientific journal articles, meetings, books, industrial standards, technical disclosure, etc. These references are termed "prior art."

[40]Personal communication with Kimberly Hamilton, CHI Research, Inc.

[41]Some caveats apply. The use of patenting varies by industry segment, and many citations on patent applications are to prior patents. Industrial patenting is only one way of seeking to ensure firms' ability to appropriate returns to innovation and thus reflects, in part, strategic and tactical decisions (e.g, laying the groundwork for cross-licensing arrangements). Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more such products in the future. (See Geisler 2000.)

Figure 5-45.
Number of citations in U.S. patents to scientific and technical articles: 1985–2000



NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references of U.S. patents issued in 2000 to articles that were published 1986–97. Changed U.S. Patent & Trademark Office procedures, greater ease of locating scientific articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and Patent Citations databases; and National Science Foundation, Division of Science Resources Statistics.

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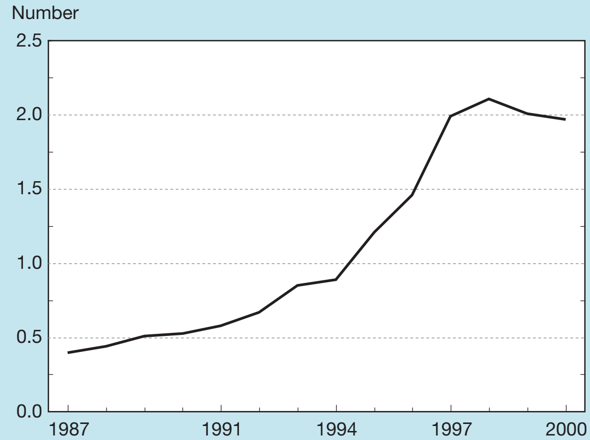
Figure 5-46.
Average number of citations to scientific and technical articles per U.S. patent: 1987–2000



NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references by U.S. patents issued in 2000 to articles that were published 1986–97. Changed U.S. Patent & Trademark Office procedures, greater ease of locating scientific articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and Patent Citations databases; and National Science Foundation, Division of Science Resources Statistics.

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The number of patent citations to articles appearing in any of the world's scientific and technical literature increased rapidly since the mid-1980s. They stood at about 22,000 in 1985, reached almost 123,000 in 1995, then more than doubled to reach more than 310,000 in 1998. (See figure 5-45.)[42] Even as the number of patents rose rapidly, the average number of citations per U.S. patent increased more than fivefold during this period. (See figure 5-46.) The rapid growth of citations ceased in 1999–2000, with total and average citations falling slightly in each of these two years.[43]

Citations to research articles were matched to a subset of approximately 5,000 of the world's most important scientific and technical journals to ascertain information about these citations: scientific field, country of publication and inventor, and performing sector (which is referenced to a smaller subset of U.S. literature) for all U.S. patents issued from 1987 through 2000. Although this eliminates references to other journals, this restricted set of citations helps provide insight on the factors driving this rapid growth of citations.

The rapid growth of article citations in patents throughout much of the past decade was centered in huge increases in the life science fields of biomedical research and clinical medicine. In 1987, each of these fields had about 3,000 citations; by

[42]The number of citations is based on scientific and technical articles published in a 12-year span that lagged 3 years behind issuance of the patent. For example, 2000 patent citations are to articles published in 1986–97, and so forth.

[43]The growth of citations likely has been influenced by changes in PTO procedures, regulations, and legal precedent. See sidebar, "The Growth of Referencing in Patents."

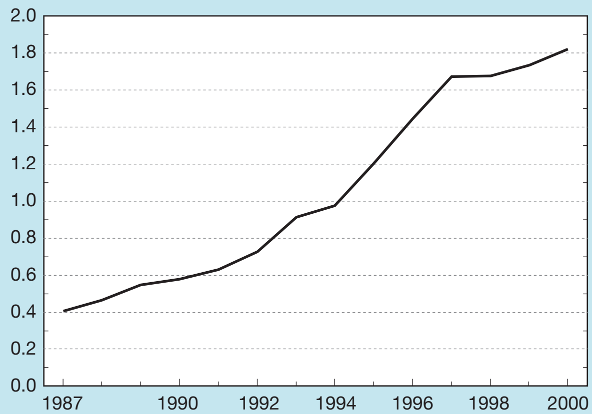
The Growth of Referencing in Patents

During the past decade, the rate at which patents reference scientific papers has increased rapidly. The causes of this growth are complex, but they appear to include 1995 changes in patent law. These changes, enacted to comply with the General Agreement on Tariffs and Trade (GATT), changed the term of protection from 17 years from the award date to 20 years from the filing date for applications received after June 8, 1995. Previously rejected patents refiled after this date would also be subject to the GATT rules. Applications submitted to the U.S. Patent and Trademark Office (PTO) more than doubled in May and June of 1995. These applications carried an unusually large number of references to scientific material. Patents applied for in June 1995 carried three times the number of science references as those from March 1995 and six times the number as those from July 1995. This sudden increase in referencing affected patents in all technologies, not just those in biotechnology and pharmaceuticals, in which referencing is most extensive.

The surge in applications during this period suggests that applicants and their attorneys rushed to file their patents under the old rules, perhaps out of caution and uncertainty about the GATT rules. One source of uncertainty in the application process at the time, affecting especially biotechnology, was ambiguity about what constituted adequate written description. Because a rejected application would have to be refiled under the GATT rules, referencing a great deal of scientific material may have been a strategy to minimize the chance of rejection because of lack of adequate written description.

Patents applied for in May and June 1995 were issued gradually over the next few years. As these patents were issued, the rate of referencing increasing rapidly. However, after the last of these applications were processed, the rate of referencing fell again to levels more nearly like those found earlier. In fact, if these patents are eliminated from consideration, a more gradual long-term trend of increased referencing is evident. (See figure 5-47.)

Figure 5-47.
Science references per U.S. patent excluding "spike" patents: 1987–2000



NOTES: Citations include all references to scientific articles. Citation counts are on the basis of a twelve-year period with a three-year lag; for example 2000 citations are references by U.S. patents issued in 2000 to articles that were published 1986–97. "Spike" patents are those with an application date of May–June 1995 and are excluded from this count.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office, CHI Research, Inc., Science Indicators and patent databases, and National Science Foundation, Division of Science Resources Statistics.

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2000, the number had risen to more than 60,000 in biomedical research and more than 40,000 in clinical medicine. Citations to these two fields accounted for about 70 percent of all citations in 2000. Although citations in other fields also increased, the huge increases in clinical medicine and biomedical research resulted in big shifts in field shares (see appendix table 5-54):

- The share of biomedical research citations rose from 24 percent in 1987 to 45 percent in 2000; clinical medicine rose from 23 to 29 percent, respectively.
- The combined share of physics, chemistry, and engineering and technology citations dropped from 49 to 22 percent between 1987 and 2000.

The bulk of patents citing scientific literature were issued to U.S. inventors, who accounted for 64 percent in 2000. The U.S. share has increased slightly over the past two decades. This share is disproportionately higher than the U.S. share of all patents. The share of Asian inventors, however, is disproportionately lower than their share of total U.S. patents. Other key inventor regions and countries of patents that cite scientific literature include Western Europe (17 percent), including France (3 percent), Germany (4 percent), and the United Kingdom (4 percent), Japan (12 percent), NIEs (2 percent), and Canada (3 percent). Since the late 1980s, the share of U.S. patents issued to Western European and Japanese inventors fell 3 to 4 points, while the share by the NIE's rose from almost zero to 2 percent in 2000. (See text table 5-23.)

Articles authored from the academic sector were the most widely cited in U.S. literature,[44] accounting for 60 percent in 2000, and were prominently represented in the life science fields, particularly biology. The rapid increase of citations to this sector increased its share from just below half in 1987, whereas shares fell in all other sectors. (See appendix table

[44] U.S. performer data is restricted to citations of U.S. literature in the ISI journal set.

Text table 5-23.
Inventor nationality of U.S. patents that cite scientific literature

Nationality of inventor	2000 U.S. patents citing scientific literature	2000 All U.S. patents	1994 U.S. patents citing scientific literature	1994 All U.S. patents	1988 U.S. patents citing scientific literature	1988 All U.S. patents
Number of U.S. patents	13,945	157,497	7,589	101,676	4,572	77,924
Percentage share of patents						
World	100.0	100.0	100.0	100.0	100.0	100.0
North America	66.9	56.2	62.3	57.1	62.2	53.9
Canada	2.5	2.2	1.6	2.0	1.6	1.9
United States	64.4	54.0	60.7	55.1	60.6	52.0
Western Europe	16.9	16.7	16.5	16.9	20.4	22.9
Germany	4.4	6.5	5.1	6.6	6.6	9.4
France	2.7	2.4	3.4	2.7	3.7	3.4
Italy	0.9	1.1	1.0	1.2	1.4	1.4
Netherlands	1.0	0.8	1.1	1.0	0.9	0.8
Switzerland	0.9	0.8	1.3	1.1	1.6	1.6
United Kingdom	3.8	2.3	2.6	2.2	4.2	3.3
Asia	14.1	25.3	19.7	24.5	15.8	21.6
Japan	11.8	19.9	18.9	22.0	15.5	20.7
Asian NIEs	2.0	5.3	0.7	2.5	0.1	0.8
Other	2.1	1.8	1.6	1.4	1.7	1.7

NOTES: Asian NIEs are newly industrialized economies of Hong Kong, Singapore, South Korea, and Taiwan. The number of U.S. patents and nationality of inventor is based on U.S. patents that reference scientific articles in approximately 5,000 journals classified by the Institute of Scientific Information.

SOURCES: U.S. Department of Commerce, Patent and Trademark Office; Institute for Scientific Information; CHI Research, Inc., Science indicators and patent database; and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

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5-55.) The increase in citations to academic articles was particularly strong in physics (28 to 46 percent); the earth and space sciences (40 to 64 percent); and engineering and technology (25 to 49 percent), which are fields with stagnating or declining industry article output. Industry was the next most widely cited sector (20 percent share). Industry articles were prominently cited in the fields of physics and engineering and technology (42 percent for each field).

Life sciences, particularly biomedical research and clinical medicine, dominated nearly every sector, with from 67 percent to almost 100 percent of all citations. (See appendix table 5-55.) The composition of citations to industry articles in life sciences, in particular, illustrates the key role of these areas of inquiry. Sectors that had prominent citation shares in the physical sciences earlier in the decade (for-profit industry and FFRDCs) had significant declines in citations to these fields, while their share of life sciences citations grew significantly.

Examining the share of cited literature in the United States, Western Europe, and Asia adjusted for their respective shares of scientific literature reveals that inventors favor their own country or region. This is similar to the pattern of citations to scientific papers. U.S. literature, however, is highly cited by foreign inventors, a trend similar to the high frequency of citation of U.S. literature by non-U.S. scientists. U.S. literature is highly cited by Western European and Asian inventors, especially in the fields of chemistry, physics, clinical medicine, and biomedical research. (See text table 5-24.) In addition, Asian physics articles are highly cited by U.S. inventors and Asian engineering and technical articles are highly cited by Western European inventors.

Patents Awarded to U.S. Universities

The results of academic S&E research increasingly extend beyond articles in technical journals to patents protecting inventions deemed to be novel, useful, and nonobvious.[45] The Bayh-Dole University and Small Business Patent Act of 1980 provided a standard framework for university patenting, which a few institutions were already undertaking, and stimulated wider use of the practice. The act permitted government grantees and contractors to retain title to inventions resulting from federally supported R&D and encouraged the licensing of such inventions to industry.

Trends in academic patenting provide an indication of the importance of academic research to economic activity. The bulk of academic R&D is basic research, that is, it is not undertaken to yield or contribute to immediate practical applications. However, academic patenting data show that universities are giving increased attention to potential economic benefits inherent in even their most basic research and that PTO grants patents based on such basic work, especially in the life sciences.

The number of academic institutions receiving patents has increased rapidly since the 1980s after slow growth in the preceding decade but appears to have leveled off within the past several years to between 175 and 184. Both public and private institutions participated in this rise.[46] (See appendix table 5-56.)

[45] Research articles also are increasingly cited on patents, attesting to the close relationship of some basic academic research to potential commercial application. See the previous section, "Citations in U.S. Patents to Scientific and Technical Literature."

Text table 5-24.
U.S. patent citations of scientific literature relative to output of scientific literature: 2000

Citing inventor country/region	Cited literature: United States	Western Europe	Asia
All fields			
United States	1.86	0.67	0.60
Western Europe	1.33	1.20	0.57
Asia	1.22	0.60	2.53
Clinical medicine			
United States	1.61	0.67	0.63
Western Europe	1.19	1.11	0.56
Asia	1.20	0.47	3.15
Biomedical research			
United States	1.27	0.64	0.51
Western Europe	1.30	1.17	0.48
Asia	1.36	0.64	1.21
Biology			
United States	1.70	0.75	0.75
Western Europe	1.01	1.55	0.77
Asia	0.76	0.72	3.62
Chemistry			
United States	2.53	0.78	0.69
Western Europe	1.53	1.35	0.73
Asia	1.49	0.79	1.87
Physics			
United States	2.24	0.49	1.10
Western Europe	1.53	1.03	1.02
Asia	1.38	0.53	2.42
Engineering and technical			
United States	1.72	0.70	0.71
Western Europe	1.05	1.38	2.13
Asia	1.25	1.08	1.66

NOTES: County/region listed by its relative citation index, an indicator of the propensity of the inventor to cite literature adjusted for the inventor region/country's share of scientific literature. A value of 1.00 would signify that the country/region's share of cited literature by U.S. patents is equivalent to its share of published literature. Citations for 2000 are for a 12 year period with a three-year lag, i.e., 1986-1997 articles in the entire ISI journal set, which consists of approximately 5,000 journals. The share of the inventor country/region's publications in the world literature is on the basis of a more restricted fixed 1985 set of ISI journals. The difference in the coverage of the journal sets means that these indexes should be treated as approximate measures.

SOURCES: Institute for Scientific Information, Science and Social Science Citation Indexes; U.S. Department of Commerce, Patent and Trademark Office; CHI Research, Inc., Science Indicators and patent database; and National Science Foundation, Division of Scientific Resources Statistics (NSF/SRS).

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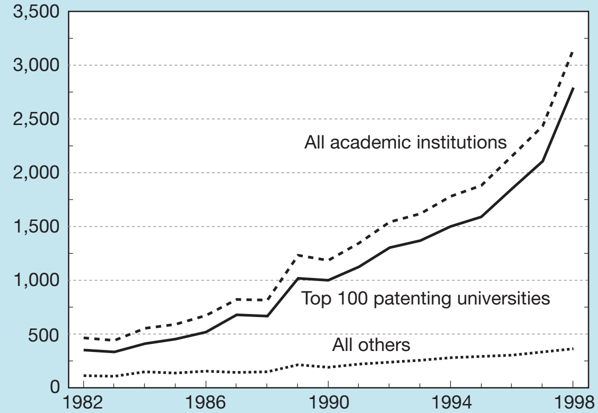
Figure 5-48.
Granted academic patents: 1982–98



NOTE: Top 100 patenting universities are determined by the sum of patents awarded during the 1990s.

See appendix table 5-55.

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The expansion of the number of institutions was dwarfed by the steep rise in the number of patent awards to academia, from about 250–350 annually in the 1970s[47] to 3,151 in 1998, accelerating rapidly since 1995. (See figure 5-48.) As a result, academic patents now approach 5.0 percent of all new U.S.-owned patents, up from less than 0.5 percent two decades ago.

During the 1990s, the 100 largest recipients of academic patents accounted for more than 90 percent of the total. This reversed a trend during much of the 1980s, when many smaller universities and colleges began to receive patents, thus pushing the large institutions' share as low as 82 percent. (See appendix table 5-56.)

The vigorous increases in the number of academic patents largely reflect developments in life sciences and biotechnology (see Huttner 1999). Patents in a mere three application areas or "utility classes," all with presumed biomedical relevance,[48] accounted for 41 percent of the academic total in 1998, up from a mere 15 percent through 1980. (See figure 5-49.)

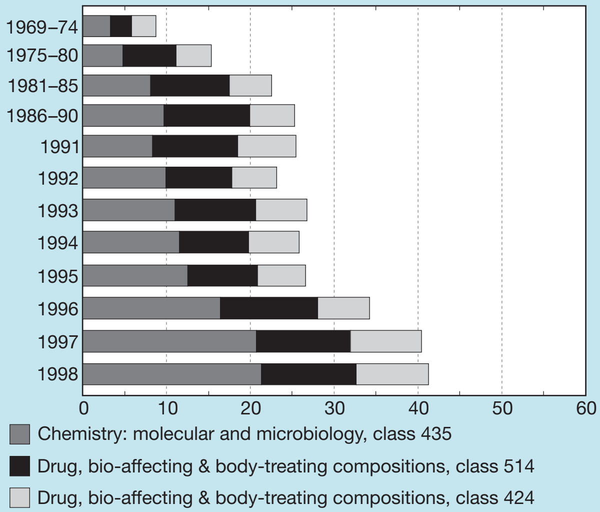
Academic institutions are increasingly successful in negotiating royalty and licensing arrangements based on their patents. Although total reported revenue from such licensing arrangements remain low in comparison to R&D spending, a

[46] It is difficult to be precise. Patent assignment depends on university practices, which vary and can change with time. Patent assignation may be to boards of regents, individual campuses, subcampus organizations, or entities with or without affiliation with the university. The data presented here have been aggregated consistently by PTO starting in 1982. The institution count is conservative, because several university systems are included in the count and medical schools are often counted with their home institutions.

[47] See National Science Board (1996), appendix table 5-42.

[48] Utility class numbers 424 and 514 capture different aspects of "Drug, bio-affecting and body treating compositions"; utility class number 435 is "Chemistry: molecular biology and microbiology." Patents are classified here according to their primary technology class.

Figure 5-49.
Percent of total academic patents in three largest academic utility classes: 1969–98



SOURCES: U.S. Patent and Trademark Office, TAF Report: U.S. Universities and Colleges; and NSF, Division of Science Resources Statistics, special tabulations.

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strong upward trend points to the confluence of two developments: a growing eagerness of universities to exploit the economic potential of research activities conducted under their auspices, and the readiness of entrepreneurs and companies to recognize and invest in the market potential of this research.

A survey by the Association of University Technology Managers has tracked several indicators of academic patenting, licensing, and related practices. Text table 5-25 summarizes this information for the 1990s. The number of license disclosures, applications, new patents, startup firms, and revenue-generating licenses and options have all grown rapidly.

University income from patenting and licenses reached $641 million in 1999, still low relative to academic research expenditures but more than double the 1995 total. About half of total royalties were classified related to the life sciences; about one-third were not classified; and the remainder, labeled "physical sciences," appears to include engineering.

New licenses and options granted have risen by half since 1995. More than half were granted to startups or other small companies, but about 40 percent went to large firms. Of particular interest is the rise in new equity licenses and options executed relative to the number of startup companies formed, indicating that universities are increasingly taking a longer view of their investments.

Text table 5-25.
Academic patenting and licensing activities: 1991–99

Indicators of activity	1991	1992	1993	1994	1995	1996	1997	1998	1999
	Millions of dollars								
Gross royalties	130.0	172.4	242.3	265.9	299.1	365.2	482.8	613.6	675.5
Royalties paid to others	NA	NA	19.5	20.8	25.6	28.6	36.2	36.7	34.5
Unreimbursed legal fees expended	19.3	22.2	27.8	27.7	34.4	46.5	55.5	59.6	58.0
New research funding from licenses	NA	NA	NA	106.3	112.5	155.7	136.2	126.9	149.0
	Number								
Invention disclosures received	4,880	5,700	6,598	6,697	7,427	8,119	9,051	9,555	10,052
New patent applications filed	1,335	1,608	1,993	2,015	2,373	2,734	3,644	4,140	4,871
Total patents received	NA	NA	1,307	1,596	1,550	1,776	2,239	2,681	3,079
Startup companies formed	NA	NA	NA	175	169	184	258	279	275
Number of revenue generating licenses, options	2,210	2,809	3,413	3,560	4,272	4,958	5,659	6,006	6,663
New licenses and options executed	1,079	1,461	1,737	2,049	2,142	2,209	2,707	3,078	3,295
Equity licenses and options	NA	NA	NA	NA	99	113	203	210	181
	Percent of national academic total represented by responding institutions								
Sponsored research funds	65	68	75	76	78	81	82	83	82
Federal research funds	79	82	85	85	85	89	90	90	90
Patents awarded	NA	NA	81	90	83	82	92	86	92
	Number of reporting institutions								
Number of institutions	98	98	117	120	127	131	132	132	132

NA = not available

NOTE: New research funding refers to research funding to an institution that was directly related to a license or option agreement.

SOURCE: Association of University Technology Managers. AUTM Licensing Survey, various years (Norwalk, CT).

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The Bayh-Dole Act may have contributed to the strong rise in academic patenting in the 1980s, although this activity was already increasing before then. However, the act did stimulate the creation of university technology transfer and patenting units and increased attention to commercially relevant technologies and closer ties between research and technological development. A landmark 1980 Supreme Court ruling (*Diamond* v. *Chakrabarty*) allowing patentability of genetically modified life forms may have been a major stimulus behind the recent rapid increases.

University patenting and collaboration with industry in the United States have contributed to the rapid transformation of new and often basic knowledge into industrial innovations, including new products, processes, and services. Other nations, seeing these benefits, are endeavoring to import these and related practices in an effort to strengthen their innovation systems. In the United States, however, the relative success of university-industry collaboration and academic patenting has raised a number of questions about unintended consequences for universities, academic researchers, and academic basic research.

Concerns have been expressed about potential distortions of the nature and direction of academic basic research and about contract clauses specifying delays or limitations in the publication of research results. The possibility exists that research results may be suppressed for commercial gain, deleterious not only to the conduct of research but potentially also to the perception of academia as an impartial seeker of knowledge. Unsettled questions also arise from faculty members' potentially conflicting economic and professional incentives in their relationships with industry or as officers or equity holders in spinoff firms.

The latter issue also arises for universities, which are moving in the direction of acquiring equity in spinoff firms they generate. They also face the question of balancing their support across different fields or concentrating on a few lucrative areas. Scholars are now asking whether academic patenting practices may in fact be undermining the intended goal of enhancing the transfer of new technologies (National Academies STEP 2001).

Conclusion

Strengths and challenges characterize the position of academic R&D in the United States at the beginning of the 21st century. Its graduate education, linked intimately to the conduct of research, is regarded as a model by other countries and attracts large numbers of foreign students, many of whom stay after graduation. Funding of academic R&D continues to expand rapidly, and universities perform nearly half the basic research nationwide. U.S. academic scientists and engineers are collaborating extensively with colleagues in other sectors and increasingly with international colleagues: in 1999, one U.S. journal article in five had at least one international coauthor. Academic patenting and licensing continue to increase, and academic and other scientific and technical articles are increasingly cited on patents, attesting to the usefulness of academic research in producing economic benefits. Academic licensing and option revenues are growing, as are spinoff companies, and universities are increasingly moving into equity positions to maximize their economic returns.

However, there are challenges to be faced and trends that bear watching. The Federal Government's role in funding academic R&D is declining, and fewer institutions receive these funds. Research-performing universities have increased their own funds, which now account for one-fifth of the total. Industry support has grown, but less than might be surmised given the close relationship between R&D and industrial innovation. Industry support barely reached 8 percent of the total in 1999, well below half of universities' own funds. Spending on research equipment as a share of total R&D expenditures declined to 5 percent during the 1990s, a trend worthy of attention.

Academic employment has undergone a long-term shift toward greater use of nonfaculty appointments, both as postdoctorates and in other positions. A researcher pool has grown independent of growth in the faculty ranks. These developments accelerated during the latter half of the 1990s, when both retirements and new hires were beginning to rise. This raises the question of the future development of these related trends during the next decade, when retirements will further accelerate. Another aspect of this issue is the level of foreign participation in the academic enterprise. Academia has been able to attract many talented foreign-born scientists and engineers, and the nation has benefited from their contributions. However, as the percentage of foreign-born degree-holders approaches half the total in some fields, attention shifts to degree-holders who are U.S. citizens. Among those, majority males have been earning a declining number of S&E doctorates, and they also have shown a disinclination to enter academic careers. On the other hand, the number of S&E doctorates earned by U.S. women and members of minority groups has been increasing, and these new Ph.D.-holders have been entering academia. This development will perhaps aid the growing numbers of students from minority backgrounds expected to enroll in college over the next quarter century by providing role models.

Questions arise about the changing nature of academic research and the uses of its results. The number of U.S. articles published in the world's leading journals is declining in absolute numbers, a trend that remains unexplained. This development follows increased funding for academic R&D and coincides with reports from academic researchers that fail to show any large shift in the nature of their research. Regarding protection of intellectual property, universities moving into equity positions raise conflict-of-interest concerns for institutions and researchers that remain unresolved. Public confidence in academia could decline should academia's research or patenting and licensing activities be perceived as violating the public interest.